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Ballistic missile defence and the politics of testing: the case of the US Ground-based Midcourse Defence

Abstract

One of the arguments of the Bush administration for the early deployment of a Ballistic Missile Defence system was not only that this would provide some limited defensive capability, but also that it would facilitate 'learning by doing'. In practice, however, this 'capability-based' deployment has failed to facilitate such technological advancement. Instead of enabling the improvement of the technology, early deployment, coupled with a series of flight-test failures, has led to a shift towards less demanding tests. Deployment has actually proved counterproductive because the need for the tests to be successful 'public experiments' has overridden any significant progression to more realistic testing.

Introduction

Much of the discourse around US plans for Ballistic Missile Defense (BMD), and much of the opposition to such a system, has focused on the issue of technical feasibility. Put bluntly, the question that is typically asked is: will it work? Is it technically possible to build a system that can defend the US against nuclear-armed ballistic missiles? Given (thankfully) the lack of operational experience, most of the weight of claims for efficacy rests on the results of testing. Flight-testing, in particular, has assumed a heavy responsibility as the means by which the performance of BMD technology is judged.

A key issue is whether the number and nature of tests is adequate to provide credible evidence that BMD would achieve the operational performance that is claimed. Opponents of BMD have argued that not only are the test results not very good, but also that the design of the tests is insufficiently similar to realistic conditions of use. Supporters of BMD, on the other hand, claim that the technology is so important that it should be developed and deployed even if the evidential basis for performance claims is limited. Moreover, they argue that further development and deployment is the only way to build up experience of the technology, and thus gain more knowledge about its performance. As BMD supporter Republican Senator Jon Kyl of Arizona put it: 'You can only do so much hypothetical testing' (Quoted in Hulse and Broad, 2004). The important thing, BMD proponents argue, is to get 'rubber on the road' by deploying something, not only gaining experience, but also demonstrating that the US is no longer prepared to follow a policy of being defenceless against nuclear attack (McMahon, 1997, 226-227).

This is not a new debate; the case for early deployment, and for the benefits of 'learning by doing' (Arrow, 1962), were also made in the first phase of BMD development – concerning what was then known as Anti-Ballistic Missile (ABM) technology. General Maxwell Taylor, Chairman of Joint Chiefs of Staff, made the same argument with relation to the Nike Zeus ABM system: 'Had we crashed [speeded up] the Zeus program we would at least have accomplished two things. One, we would now be learning by doing. As far as my experience goes with new weapons, that is the only way you can make any great progress. It takes a considerable amount of actual employment of weapons systems to get the best out of them' (Quoted in Yaneralla, 1997, 93).

Although Nike Zeus was not deployed, its more capable successor, Nike X, comprised the technical basis for the Safeguard ABM system that was declared

operational in October 1975. Again the argument was made that deployment would provide a way 'to check out the entire system under realistic conditions and work out the problems that inevitably arise in the deployment of any new major weapon system' (Office of the Secretary of Defense, 1969, 3). In practice, this did not happen because Safeguard had an operational life of only a few months, with Congress voting to deactivate the system due to its widely acknowledged shortcomings. In that instance, early deployment proved far from beneficial, particularly given that - as is clear from documents in the Nixon archivesⁱ - hardly anyone in the government, the armed services, or the contractor building the system thought it would be effective.

Over thirty years later, the argument is again being made for early deployment of BMD technology. Again, however, this appears problematic. The dilemma for flight-testing of the Ground-based Midcourse Defense (GMD) technology now deployed in Alaska and California is that the tests have to do two things at once. They are what Collins (1988) has called 'public experiments', with both the general public, and more specifically politicians in Congress, providing audiences that need convincing that missile defence is both feasible and value for money. At the same time, however, flight-tests are a key tool for the developers of the technology, providing empirical feedback on performance that is unobtainable from simulation or ground-testing of individual components.

With flight-testing having such a high profile in the debate over the technical feasibility of BMD, testing is highly political, with a tension between fear of failure and knowledge advancement. On the one hand, the public and political attention given to test results has led the Missile Defense Agency to adopt a conservative approach to flight-testing in the hope of avoiding too many failures. On the other hand, however, this means that the tests are less stressing, yielding fewer knowledge gains to aid technology development.

This paper will describe the origins and development of the US Ground-based Midcourse Defense (GMD) system, and in particular, its flight-testing programme. Deployment of this system was instigated by the administration of G. W. Bush in 2002, and as of January 2008 there were 21 interceptor missiles installed in Alaska and 3 in California.ⁱⁱ Other parts of the system are still under development and the overall operational readiness of the system is questionable, although it was claimed to have been raised to operational status when North Korea planned to carry out missile testing in the summer of 2006 (Gard and Isaacs, 2006).

Early Developments in Ballistic Missile Defence Technology

BMD technology is very challenging because the reentry vehicles from intercontinental ballistic missiles (ICBMs) travel at velocities of around 7km/s or 15,700 mph (see Weiner, 1984, for an excellent introduction to the topic). Ballistic missile defence thus has to function within a demanding timeframe, especially if political authority is required to give the go-ahead, and high guidance accuracy is required to intercept the reentry vehicles. Early US BMD systems mitigated guidance limitations through the use of nuclear warheads on the interceptor missiles. These warheads were optimized to emit nuclear radiation that would render incoming enemy warheads ineffective. Ground-based radars were designed to detect and track the reentry vehicles and also to guide the interceptor missiles close enough for the radiation from the nuclear warhead to disable the enemy warheads.

This ABM technology was deployed by the US in the Safeguard system that was declared operational in 1975, but closed down within months. By then the ABM Treaty, agreed by the USA and Soviet Union in May 1972 and amended in 1974,

had limited each nation to just one ABM site. Rather than being the first step on which further advances could be based, as the US Army had hoped, the Safeguard site at Grand Forks, North Dakota was widely accepted as being ineffectual, as well as expensive. Amongst the reasons for Safeguard's dwindling support, even within the Army - along with doubts about whether it would work - were concerns about the wisdom of using nuclear warheads as part of the defence.ⁱⁱⁱ This had contributed to public disquiet about ABM deployment, especially in the earlier incarnation known as Sentinel that was to be deployed near cities, but it also concerned the military. It was thought likely the defence's own nuclear detonations could blind the defensive radars - probably the biggest weakness of Safeguard was its reliance on a small number of radars - and also might prevent the launch of the US Minuteman missiles that it was supposed to be protecting.

Following the demise of Safeguard, the US Army pursued a different approach to BMD. As early as the 1960s studies showed the potential for using infra-red to detect objects against the very cold background of space. These studies indicated that it should be possible to 'see' reentry vehicles at distances of over a thousand miles using telescopes based on infra-red sensitive semiconductors (Davis, 1997). Using homing guidance, such technology offered the possibility of a defence based on 'hit-to-kill', in which the defensive interceptors physically collide with the incoming warheads. Although very challenging, this approach had the great benefit of not involving nuclear warheads. Indeed, no explosive at all is required because the collision of even small masses at such high velocities is highly destructive.

Strategic hit-to-kill (i.e. of intercontinental range missiles) was first demonstrated in the Homing Overlay Experiment (HOE) tests carried out in 1983-84 (Mann, 198x). Although only the last of these four test flights was considered fully

successful, the overall impression given by HOE was that hit-to-kill was feasible. However, this approach was then marginalised in the rush to develop more exotic technologies and approaches in President Reagan's 'Star Wars' Strategic Defense Initiative (SDI). In particular, Secretary of Defence Casper Weinberger had a 'strong desire ... not to let the programme sink back into a familiar mode of solely ground-based, largely ineffective, defensive systems' (Weinberger, 1990, 221).

Nevertheless, a second phase of hit-to-kill tests was carried out in 1991-92 in the Exoatmospheric Reentry Interceptor Subsystem (ERIS) programme, with a success rate of one out of two flight tests.^{iv} Although SDI continued to favour space-based approaches such as Brilliant Pebbles, the purported success^v of the Patriot in the first Gulf War of early 1991 had a significant impact on the US political mood in relation to missile defence (McMahon, 106-107). Two 'lessons' of this experience were significant. First, that missile defence could provide some protection from attack, and even if not perfect, it would be better to have it than not. Second, that deterrence would not necessarily prevent attack; just as Iraq was not deterred from attacking US forces based in the Gulf, so, perhaps, North Korea would not be deterred from attacking the US. Although, the performance of Patriot was later judged to be very poor (Postol, 1991/92), and the relevance of the Iraqi example to threats involving the use of nuclear weapons against the USA was questionable, the episode prompted a bipartisan Congressional shift towards support for 'hit-to-kill' BMD. Republican missile defence supporters in the Congress were able to build a consensus around the perceived lessons of the Gulf War, but without recourse to the politically divisive space-based technology of Star Wars.

National Missile Defence Development and Testing under Clinton

Further impetus for missile defence came during the Clinton administration as the concern over the missile threat posed by 'rogue states' rose up the political agenda (Graham, 2001). Such arguments became hard to resist when the Democrats lost control of the Congress in the 1994 mid-term elections. In 1995 Congress passed a Ballistic Missile Defense Act that specified that deployment of a BMD to defend the US should begin in 2003. Although unenthusiastic, the Clinton administration agreed to a 'three-plus-three' plan whereby a National Missile Defense (NMD) system should be demonstrated in (roughly) three years with the potential then to deploy if necessary within another three years (Graham, 2001, 27).

Such a demonstration of feasibility was seen to hinge on the performance of flight-tests. Earlier test programmes had been seen as demonstrating that it was possible to 'hit a bullet with a bullet', to use the usual analogy, but two main issues remained a concern. For one thing, the combined success rate for HOE and ERIS was 2 out of 6, and a system with such a one in three chance of hitting the target would be unacceptable for a deployed defence.

The other issue, however, is more fundamental to disputes over performance claims for BMD. Hitting a re-entry vehicle in a flight-test is an impressive achievement, but the critical issue is whether the conditions of such tests are sufficiently realistic. That is to say, confidence in the system hinges on judgements of similarity between the flight-tests and 'real-life' use (MacKenzie, 1989). Typically, in a flight-test the nature of the target, any accompanying decoys or other countermeasures, and their time and direction of attack are all known to the defence. Moreover, to date, most tests have used decoys that are

relatively easy to distinguish from the target re-entry vehicle or no decoys at all (Gronlund et al, 1994). As Paul Kaminski, Undersecretary of Defense for acquisition and technology from 1994 to 1997, put it: 'We can make a bullet hit a bullet. We can demonstrate that under ideal conditions. The next step is to move from hitting, not occasionally, but to hit routinely under stressful operational conditions' (Quoted in Weiner, 1997).

NMD flight-testing was carried with interceptors based on the Kwajalein atoll in the Marshall Islands, and using radars and other sensors based there. The target objects, typically a reentry vehicle and some decoys, were carried by missiles launched from the Vandenberg Air Base in California, about 7500 km away (Gronlund et al, 1994). These target reentry vehicles carried either a GPS receiver and transmitter or a C-band beacon (for use with a C-band radar on Hawaii) or both because no suitable radar could track the early stages of flight unassisted. Interceptor launch was initiated and guided by information from these sources, but the final homing of the kill vehicle (known as the exo-atmospheric kill vehicle or EKV) was autonomous. As it approaches the target cluster (the reentry vehicle, remnants of the missile, and any decoys and countermeasures), the EKV compares the infrared signatures of the objects it can see and uses discrimination algorithms to choose its target.

The first two Integrated Flight Tests (IFTs 1A and 2) were 'fly-by' tests aimed at demonstrating the performance of the system, and particularly the competing kill vehicle designs of Boeing and Raytheon, but with no attempt to intercept the target reentry vehicle. Carried out in June 1997 and January 1998 respectively, these tests collected data as the kill vehicle viewed the dummy warhead and its accompanying decoys, which comprised both a number of different sized balloons and conical, reentry vehicle-shaped, decoys (Coyle, 2000).

Although not intended to achieve intercepts these fly-by tests were to be significant for future test plans, leading to a major controversy over the capability of the kill vehicle to discriminate between decoys and actual reentry vehicles, and whether the tests were a realistic test of such a capability. At the heart of this controversy was the decision by the Ballistic Missile Defense Office to reduce the number and complexity of decoys used in subsequent flight tests.

Critics argue that this decision stemmed from the realization that the kill vehicle's discrimination algorithms could not distinguish between realistic decoys and the actual reentry vehicle (Postol, 2000). Certainly, whatever the reason, decoys that have been used in subsequent flight tests have had markedly different signatures from the target reentry vehicle. This was confirmed by Philip Coyle, the Pentagon's Director of Operational Test and Evaluation, in Congressional testimony in September 2000: 'Signature simulations show that since the large balloon and deployment bus have infrared (IR) signatures very dissimilar to the MRV [medium reentry vehicle], the EKV can easily discriminate the MRV from these objects' (Coyle, 2000).

The final three flight-tests carried out during the Clinton administration, IFTs 3 to 5, aimed to intercept the target reentry vehicle, with only one reported success, in the first attempt on 2 October, 1999. The second attempt, IFT 4, on 18 January, 2000, was unable to home on the target because of a failure with the plumbing of the cooling system required to get the infrared seeker down to a sufficiently low temperature to enable it to distinguish the infrared signature of the target from background noise. IFT 5 on 8 July, 2000 also failed, in this instance because the kill vehicle did not separate from the booster (Graham, 2001, 199-200, 299-303).

With only one hit out of three attempts Clinton was able to argue that the technology was too immature to make a decision to deploy, and in September

2000 he decided to defer a deployment decision, leaving the matter open for the next administration (Graham, 2001, 328-331). The President said that he did not have 'enough confidence in the technology, and the operational effectiveness of the entire NMD system, to move forward to deployment' (Quoted in Gronlund et al, 2000).

Of course, it could be argued that even had there been three perfect intercepts this would hardly have constituted a sufficient case for a deployment decision. The tests were acknowledged to be not very challenging of discrimination capability. According to Major General Willie Nance, the program executive officer for the ground-based missile defence: 'I will tell you that these are not stressing discrimination tests. We don't intend that. These tests are principally focused on demonstrating we could do hit to kill' (Quoted in Gronlund et al, 2004, 16).

Indeed according to Congressional testimony by Pentagon test director Coyle the test programme was not designed to support an immediate deployment decision, but rather to add to the knowledge base for the technology:

The testing program has been designed to learn as much as possible from each test. Accordingly, the tests so far have all been planned with backup systems so that if one portion of a test fails, the rest of the test objectives might still be met. Developmental tests in a complex program, especially those conducted very early, contain many limitations and artificialities, some driven by the need for specific early design data and some driven by test range safety considerations. Additionally, the tests are designed so that they will not produce debris in orbit that will harm satellites. Also, the program was never structured to produce operationally realistic test results this early. Accordingly, it was not realistic to expect these test results could support a full deployment decision now, even if all of the tests had been unambiguously successful, which they have not been (Coyle, 2000).

Missile Defence under G. W. Bush

Once elected, the Bush administration quickly increased funding for missile defence^{vi}, and in December 2001 made the significant step of announcing US withdrawal from the ABM Treaty, to take effect six months later on June 13, 2002. Without the constraints of the ABM Treaty the US was free to deploy missile defence systems of whatever type and number it decided, and at any locations. The NMD technology was renamed as the Ground-based Midcourse Defense (GMD) and made the centerpiece of US BMD efforts. These were reorganized, bringing all the main service activities (for example, the Army's Theater High Altitude Area Defense Program, the Navy's ship-based Aegis system, and the Air Force's airborne laser, amongst others) under the control of the Missile Defense Agency (MDA), as the Ballistic Missile Defense Office was renamed.^{vii}

MDA's initial plan was to construct a 'Test Bed' in Alaska, with the rationale that this would enable more realistic testing: 'How do you realistically test an enormous and complex system, one that covers eight time zones and engages enemy warheads in space? The answer is that we have to build it as we would configure it for operations in order to test it. That is exactly what we are doing by building our test bed and putting it on alert this year' (Kadish, 2004).

This viewpoint was also supported by the new Pentagon test director, Thomas Christie, who told the Senate Armed Services Committee that: 'The test bed, including missiles, will provide an early opportunity to acquire valuable ground test data on intra- and interoperability between the command and control center and the silo/missile complex; on the system and missile health and status or built in testing capability; and on system safety, reliability, maintainability and logistics supportability. It will also permit us to get an early start on collecting data on aging effects on the missile' (Christie, 2003).

The test bed was to include interceptor missiles based in silos at Fort Greely on the Alaska mainland, as well as on Kodiak Island, and upgrades to the Cobra Dane and Beale radars located in Alaska and California. Along with the necessary communications and battle management facilities, this test bed would not only 'provide us with an excellent capability to test the integrated Ballistic Missile Defense System against more challenging targets under more realistic flight conditions', but also 'may have some capability to defend against an actual threat in a real attack' (Christie, 2003).

Critics, however, saw the test bed development as simply an excuse to begin work on BMD deployment. They argued that the test bed was not suited to realistic testing of the GMD system. In particular, the interceptors based at Fort

Greely could not be used for test purposes because missile flights over US territory were banned for range safety reasons. Nor was the fixed orientation Cobra Dane radar directed towards the test range (Gronlund et al 2004, 7).

In fact, during the first two years of the Bush administration testing of the GMD system followed a similar pattern to that followed under Clinton for NMD. As before these tests were carried out with interceptors based at Kwajalein against targets launched from California, but with initially much greater success. All of the first four attempted intercepts (IFTs 6 to 9) – carried out during 2001 and 2002 – were reported as direct hits. Of these, IFT-8 was the first GMD intercept flight test to incorporate more than one decoy, with the large balloon used previously supplemented by two small balloons.

MDA Director Kadish described the approach thus: ‘Our test philosophy is to add step-by-step complexities over time such as countermeasures and operations in increasingly stressful environments. This approach allows us to make timely assessments of the most critical design risk areas. It is a walk-before-you-run, learn-as-you-go development approach.’ In particular, Kadish stressed that ‘if we were to rush to add complexity to our flight tests ... a test failure would make it very difficult to identify the actual cause of failure.’ According to Kadish: ‘Our test evaluators cannot learn by overloading system components with multiple test requirements and testing them too early under highly stressing conditions’ (Kadish, 2001; see also Broad, 2001).

Everything thus seemed to be going to plan; a plan in which, according to Kadish, the ‘testing program is designed to become increasingly realistic. ... The tests become progressively more stressful, involving, among other things, greater discrimination challenges, longer ranges, higher closing speeds, and day and nighttime shots’ (Kadish, 2001). However, this apparently smooth transition in

testing would not play out quite so ideally, and to a large extent the problem was self-inflicted as the Bush administration precipitated its own 'rush to failure', to use the words of a earlier review of the Clinton NMD programme.^{viii}

Ironically, it was the decision by President Bush to push ahead with BMD deployment that would mark the end of any semblance of a smooth progression through increasing degrees of testing realism. On December 17, 2002 President Bush issued National Security Presidential Directive 23 directing that the US begin deployment of a ground-based BMD system that would reach initial operational status in 2004 (Gronlund et al, 2004, 1). Based around GMD technology, the plan was to have 10 interceptor missiles in place by the end of 2004, with the intention of providing protection against missiles launched from Northeast Asia and the Middle East.

A Capability-based System

The Bush administration's plans for BMD deployment turned the Clinton concern with technological feasibility on its head. Instead of tying a decision to deploy to meeting a particular performance threshold, the Bush approach was to deploy whatever capability was possible, and then to build on this initial deployment with further improvements. This was known as a 'capability-based' approach, and the further improvements were to be implemented through what called 'spiral development' - a term borrowed from software development (Coyle, 2003; see also Samson and Schwellenbach, 2008).

According to MDA Director Kadish, 'The President's direction recognizes that the first systems we field will have a limited operational capability. He directed that we field what we have, then improve what we have fielded. The President thus codified in national policy the principle of Evolutionary, Capability-Based

Acquisition and applied it to missile defense' (Kadish, 2004). Kadish put the best light on this approach by stressing its flexibility: 'A capability-based approach relies on continuing and comprehensive assessments of the threat, available technology, and what can be built to do an acceptable job, and does not accommodate a hard requirement that may not be appropriate' (Kadish, 2004). During congressional hearings, Republican Senator John Cornyn from Texas, supported the White House move: 'If we waited until we went through a traditional test and operation before we then concerned ourselves with possibly deploying these in the case of emergency, it really might be too late' (Quoted in Fryer, 2005).

The potential for 'learning by doing' was also stressed as one of the benefits of early deployment. Secretary of Defense Donald Rumsfeld argued that: 'In the case of missile defense, I think we need to get something out there, in the ground, at sea, and in a way that we can test it, we can look at it, we can develop it, we can evolve it, and find out – learn from the experimentation with it' (Quoted in Firestone, 2003).

It was recognized that the initial capability offered by such a defence might be limited, but argued that it was better than nothing. Even if its effectiveness was in doubt, it was claimed that the deployment of a limited BMD capability could serve a purpose because it would complicate 'a prospective opponent's calculation of success, adding to his uncertainty and weakening his confidence' (Lucas Fischer, deputy assistant of state for strategic affairs speaking to Danish parliament, quoted in Gordon and Myers, 2001). Kadish also stated that: 'I must emphasize that what we do in 2004 and 2005 is only the starting point—the beginning—and it involves very basic capability. Our strategy is to build on this beginning to make the BMD system increasingly more effective and reliable against current threats and hedge against changing future threats' (Kadish, 2004).

The Special Status of the GMD System

The urgency felt for BMD deployment also meant that the Bush administration accorded the programme special status. In January 2002 Secretary of Defense Rumsfeld directed that BMD would be exempt from the Operational Requirements Documents and other requirements that might impede rapid decisions and progress (Canavan, 2003, 77). This meant for example that MDA had 'unique flexibility to make changes to its strategy – including revising its goals or making trade-offs among the seven BMDS elements – without necessarily having to seek prior approval from a higher-level DOD acquisition executive, as most other major acquisition programs are required to do' (GAO, 2006, 4.).

MDA was able 'to effectively defer the application of DOD acquisition regulations' (GAO, 2006, 31). So long as any element of BMD is not transferred to a military service for 'production, operation, and sustainment', MDA has discretion to vary the pace of development, and trade-off one BMD capability against another. Nor were BMD elements required to meet the normal 'cost and schedule estimates and formal performance requirements' mandated by statute for a major acquisition programme (GAO, 2006, 32).

The on-going development status of the initial BMD deployment also meant that MDA avoided conforming with regulations requiring operational testing of US weapons system prior to moving to production. This 'fly-before-you-buy' approach was first proposed by Deputy Secretary of Defense David Packard in the early 1970s, and an independent office to oversee this was finally established in 1983, with the creation of the office of the Director, Operational Testing and Evaluation (DOT&E) in the Department of Defense. Reporting both to the

Secretary of Defense and Congress, DOT&E is responsible for overseeing the operational testing of major weapons systems.

This testing should be carried out across a range of realistic operational conditions using standard equipment and conducted by the Service Operational Test Agencies overseen by the DOT&E.^{ix} Major weapons acquisition programs should not move beyond what is known as a 'low rate of initial production' (LRIP) until this operational testing has been carried out and evaluated by the DOT&E in a 'beyond-LRIP report' (Sessler et al, 2000, 92).

However, the initial Block 2004 deployment was not considered to involve a full-scale production decision and so was not seen as requiring a full assessment of its operational effectiveness. As the GAO noted in 2003, the Block 2004 GMD 'is not connected with a full-rate production decision that would clearly trigger statutory operational testing requirements' (GAO, 2003a, 19-20).

The Block 2004 GMD Deployment

Block 2004 was originally planned to provide an initial capability, known as Limited Defensive Operations (LDO), by the end of September 2004, with five GMD interceptor missiles based at Fort Greely in Alaska. Early warning and tracking would be provided by the Defense Support Program (DSP) satellites, and the upgraded Cobra Dane and Beale radars, along with Navy Aegis surveillance and tracking ships based in the Sea of Japan. As well as GMD and Aegis, Block 2004 was to incorporate a third element of the MDA's BMD technology developments, the Command, Control, Battle Management and Communications (C2BMC) system. Although these BMD capabilities were in place by the LDO date, the system was not officially activated (GAO, 2005, 13).

By the end of Block 2004 (the end of 2005) a further 15 interceptors were to be deployed at Fort Greely and Vandenberg Air Force Base in California, a sea-based X-band radar (SBX) was to be deployed, and Aegis ships were to provide some interceptors as well as radar coverage. Further radar coverage was also to be provided from the upgraded Fylingdales BMEWS in England.

In fact, GMD interceptor emplacement did not meet this planned schedule. Five interceptors were emplaced at Fort Greely by the LDO of September 2004, but only four more interceptors (two at Fort Greely and two at Vandenberg) were fielded in FY2005. One problem causing this delay centred on technical difficulties with the exoatmospheric kill vehicle (EKV); another set-back resulted from an explosion at a facility producing motors for one of the boosters (see GAO, 2006, 10-11 and 19). By the end of 2005 a total of ten GMD interceptors were in place, rather than the twenty originally planned (GAO, 2006, 19).

Radar developments also failed to match the original goals of Block 2004 (GAO, 2006, 20, 46, 50). The Forward-Based X-Band Transportable (FBX-T) radar had completed development, but negotiations with the host nation, Japan, were not completed in time. Both Cobra Dane and Beale radars were ready for operation, but there were doubts about software deficiencies and lack of testing. The use of Aegis ship-based radars for surveillance and tracking in support of GMD interception also remained untested. Two GMD tests were planned to include Aegis, but this did not occur in IFT-13C due to bad weather conditions or in IFT-14 due to fleet scheduling conflicts (GAO, 2006, 48). As it happened these tests failed anyway (see below) and the subsequent rescheduling of the GMD flight test programme has not included any use of Aegis.

(Not) Testing Through Failure

Ironically, the decision to deploy the GMD system coincided with a long hiatus in flight-testing. Up to that point MDA's approach to testing, as enunciated by MDA Director Kadish in 2001, was to 'test-though-failure' (Quoted in Wall, 2004, 30). Indeed, Kadish extolled the benefits of learning from failure:

We expect steady progress toward success, even though we anticipate we will have test failures—failures are an inevitable part of the development process. Given the integrated approach we desire to take with our missile defenses, and given that many technologies can be shared among the different BMD systems, success for one is success for all. And likewise, the failures we experience in one test can provide lessons learned applicable to all BMD development programs. Indeed, from my standpoint, if we do not fail occasionally, we are not pushing the envelope sufficiently (Kadish, 2001).

In practice, this sanguine view of failure proved very short-lived. Following the failure of test flight IFT-10 on 11 December 2002 the policy of testing through failure was abruptly dropped and there would not be another attempted intercept flight test until December 2004, and a successful intercept would not be achieved until 1 September 2006.

IFT-10 failed because the EKV did not separate from the booster due to a broken pin in an integrated circuit. This was caused by vibration induced fatigue and had not been observed in earlier flights because foam material had been used to reduce the severity of the flight vibration (GAO, 2006, 27). Most of the flight-tests

planned for 2003 and 2004 were then postponed (Wall, 2004, 30). IFT-13C in December 2004 failed due to a timing problem with the interceptor flight computer that meant it did not launch (GAO, 2006, 51).^x

IFT-13C was considered 'of particular significance because it was to have demonstrated operational aspects of the LDO capability for the first time in a flight test environment' (GAO, 2005, 16). IFT-13C was the first flight test to use the same technology (hardware and software) that was being used in the initial deployment. Rather than a surrogate booster and prototype kill vehicle as used in previous tests, IFT-13C used the operational kill vehicle along with an Orbital Sciences booster. Described as a 'zero-offset flyby', IFT-13C did not have interception of the target as a test objective, but no action would be taken to prevent an intercept occurring. In addition, IFT-13C was also planned to incorporate the use of Aegis as a fire-control radar, both tracking the target and providing the information to generate the flight plan for the interceptor. However, as it happened, even before the launch failure, the use of Aegis was cancelled due to poor weather (GAO, 2005, 16).

Only one of the planned intercept flight-tests (IFT-14 in February 2005) was carried out, with another failure; this time the interceptor missile failed to launch due to corrosion and out-of-date equipment in the silo (GAO, 2006, 27). As a result the next two intercept flight-tests were postponed as the GMD programme was rescheduled (GAO, 2006, 11). The failure of IFT-14 was particularly significant because this test had been identified by the GAO as key to demonstrating that a number of critical technologies were sufficiently mature to move to product development. This technology readiness level (TRL 7, on a scale of 1 to 9) requires that 'a pre-production prototype of the technology must be demonstrated to its expected functionality in an operational environment' (GAO, 2003b, 10-11). Three critical technologies were expected to be demonstrated in

IFT-14: the on-board discrimination capabilities of the EKV; the guidance, navigation, and control technology of the EKV, including the inertial measurement unit and divert hardware; and the in-flight interceptor communications system which provides the boosters with information required to attain the desired flight path to put the EKV on an intercept trajectory (GAO, 2003b, 12-15).

The 2005 Independent Review Team

The consecutive failures of flight-tests IFT 10, 13C and 14 led MDA Director Lt. General Henry A. 'Trey' Obering (who had taken over from Kadish in July 2004) to instigate an Independent Review Team (IRT) in February 2005.^{xi} The main recommendation of the IRT report, submitted at the end of March, was that the GMD programme should enter a new phase that they called 'The Performance and Reliability Verification Phase'. In particular, the IRT recommended that 'mission assurance becomes the highest priority objective', and stressed the importance of successful tests in sending 'a strong message to adversaries of the US, who might be dissuaded by the effectiveness of the system from investing further in ballistic missiles and/or be deterred from attacking the US, our deployed forces, our allies, and friends' (IRT, 2005, 4 & 7). In other words, it was important to make sure the tests were successful because this determined public perception of the capability of the system.

Although each of the three test failures had specific explanations, the IRT concluded that there was a general problem with the GMD programme. In particular, the demanding schedule for deployment had meant increased risk of failures, and the IRT recommended that from then on the test programme should be 'event-driven rather than schedule-driven' (IRT, 2005, 11). Rather than a

mindset of having to 'prove why should not fly', the flight readiness process should be orientated proactively to one of 'prove why should fly' (IRT, 2005, 14). Problems should not be addressed narrowly and fixed in isolation, but rather should be subject to comprehensive reviews.

A new position – Director, Mission Readiness – was established in the MDA with the primary role of examining the GMD test programme, which was restructured 'to place more emphasis on successful ground tests prior to each flight' (GAO, 2006, 36). A new round of flight-tests started with relatively simple objectives. Thus the first test (FT-1) in the restructured schedule, in December 2005, was a successful non-intercept test of interceptor operation in space, demonstrating the GMD booster launch and the separation of the EKV (GAO, 2006, 11-12, 36).

The next flight-test in the restructured schedule, and the first successful interception for almost four years, was carried out on 1 September 2006. This was the first GMD intercept test to use an operational radar (in this case Beale) rather than a surrogate radar for fire control (GAO, 2006, 52). Even more significant, however, was the fact that this test used a different intercept geometry than previous tests, with the target missile launched from Kodiak island and the interceptor from Vandenberg Air Force Base (rather than the target from Vandenberg and the interceptor from Kwajalein). However, the MDA's sensitivity to political criticism and/or lack of confidence in the technology meant that the flight test was advertised not as an intercept attempt, but rather as a sensor test:

You know, you don't accidentally hit something. If it was just a fly-by mission you don't just, oh gosh, we accidentally hit it! ... Well, I guess it gets back to, a lot of it is politics, Congress has been, you know, especially the Democrats have been jumping up and down because there has been a hiatus in the test program.^{xii}

A year later, on 28 September 2007, essentially the same test was successfully repeated (although an earlier attempt in May had been aborted due to the failure of the target missile to reach the required altitude). However, despite these test successes some missile defence supporters continue to criticize the programme for what they see as two main failings. First, the promise of spiral development has not been sufficiently followed through. Second, although there have been recent flight-test successes, these have not been accompanied by increasing realism in the design of these tests.

Lack of Spiral Development

Since the decision was made to deploy the GMD system, MDA has been preoccupied with two main tasks: the deployment itself, including the construction of interceptor sites, radar modernisation, developing the command and control system (with its heavy software demands), and so on; and sorting out the problems that were plaguing the flight-test programme. Not surprisingly, the updating of the deployed system through spiral development has suffered as a consequence. In essence, the system was deployed with the existing limited capability, but further improvement has been limited. This has left many supporters of missile defence frustrated because it undermines the rationale of a capability-based approach: 'If you want to do capability-based, it logically follows you've got to spiral development. You can't do one without doing the

other.^{xiii} Thus in September 2005 the Senate Defense Appropriations Sub-Committee complained that:

It is particularly troubling that the MDA is taking steps which, if continued, will sub-optimize the capability of and investment in the GMD element of the ballistic missile defense system. Contrary to repeated Defense Department statements on spiral development and block upgrades for the missile defense program, MDA at best plans only marginal improvements to the capability of the GMD program's Ground-based Interceptor. ... After many years of investment in this midcourse interceptor, MDA has now essentially decided that the first generation GBI [ground-based interceptor] will also be its last generation GBI (Senate, 2006).

Staunch missile defence supporters have been some of the fiercest critics of the lack of spiral development:

Remember we used to have performance requirements that the system had to meet. Remember the old-fashioned notion. Well, Rumsfeld said to Kadish, you don't have to do that. We'll deploy because it's more important to get something out there, something rather than nothing. And that's an argument. OK, so we got something out there but we know that it's not what it should be. OK, well, we're going to do spiral development, we're going to do upgrades every two years and I don't think we're doing it, we're not doing it adequately.^{xiv}

Moreover, skeptical missile defense supporters have complained about an approach that 'extols the virtue of spiral development without due acknowledgment of the importance of adequate testing to demonstrate that the product being deployed actually works' (Orman and Fox, 2007). They point out that the MDA's spiral development approach has led to 'a relaxation in the requirement of how a weapon system will be expected to perform, tending toward an acceptance of the capability it produces.' The consequence of this is that:

We have a system based in Alaska and in Vandenberg Air Force Base in California, and although some of the elements have been in place for more than three years, we do not yet know at what level they will perform. How can we determine the best ways to move forward without adequate testing? Spiral development may have significantly eased the task of developers, but without proper testing, it leaves the military services in the unfortunate position of being uncertain of how a system will perform (Orman and Fox, 2007).

Even where spiral development is being carried out, it is at such a slow pace as to undermine any claims of operational readiness. Although the MDA was aware 'by the end of Block 2004 ... that the performance of some Ground-based interceptors could be degraded because the interceptors included inappropriate or potentially unreliable parts ... the process of retrofitting these interceptors ... will not be completed until 2012' (GAO, 2008, 35). One disappointed supporter of BMD noted that despite the deployment of the GMD interceptors, 'the current missile defense system is in no way sufficient to deal with the range of present

and potential ballistic missile threats facing the United States' (Trachtenberg, 2006).

Learning by Doing, Fear of Failure, and the Testing Paradox

This lack of spiral development is, of course, closely tied to what has happened with flight-testing. A particular problem with the Bush strategy for BMD has been that its 'capability-based' deployment, predicated on the promise of continuous improvement through spiral development, coincided with a period of four years without a successful flight-test intercept.

The GMD deployment thus went ahead without the system being validated by flight-tests. The 2005 Defense Authorization Act had 'directed DOD to conduct an operationally realistic test of the system by October 1, 2005' (GAO, 2005, 18), but this did not happen. According to MDA Director Kadish the urgency of immediate deployment had required the normal procurement approach of 'fly-before-you-buy' to be replaced by one of 'fly-as-we-buy' (Wall, 2004, 30). In fact, as it turned out, in practice it was rather an approach of 'buy-before-you-fly'!

However, this lack of flight-testing was not the biggest irony of the Bush deployment decision. Paradoxically, deployment also may have undermined the role of flight-testing in improving the performance of GMD technology. Flight-test failures not only meant a long period without a successful intercept, but they also stymied the planned progression to more realistic test scenarios. Instead of facilitating 'learning by doing' the decision to deploy has compromised the flight-test programme, one of the key tools for advancing knowledge about the technology's performance.

This undermining of flight-testing has come about because of the role that these tests also play as 'public experiments' (Collins, 1988). By deploying the GMD system the Bush administration made flight-testing more sensitive politically. The technical challenges remained the same, but the societal challenges increased considerably. The more that the GMD system was portrayed as a deployed, operational system, the less tolerant the public and Congress would be of test failures. Flight-test failures now became much more significant because each failure adds to the perception that the deployed system is ineffective, even though BMD development has been costing the US taxpayer around \$10 billion a year.

The combination of deployment with flight-test failures may thus have led to a fear of failure within MDA. Earlier in the programme, MDA Director Kadish had stressed that 'from my standpoint, if we do not fail occasionally, we are not pushing the envelope sufficiently' (Kadish, 2001). However, this philosophy did not survive repeated failures, and the recent tendency of MDA has been to avoid pushing the envelope in its flight-test design.

This is significant because flight-tests cannot comprehensively replicate all possible operational scenarios. Apart from anything else, the sheer cost of flight-tests (around \$100 million a shot) means that they are limited in number. Range safety limitations, and the time it takes to verify a new intercept trajectory, also mean that only a few intercept geometries can be flight-tested. This means that to date GMD testing has involved many fewer flight-tests than previous comparable systems. For example, 165 flight-tests were carried out on the development of the interceptor missiles used in the Safeguard BMD system that was deployed in 1975 (Coyle, 2000), more than an order of magnitude more than those for the NMD/GMD technology.

Instead, increasing use has been made of modeling and simulation to carry out 'virtual testing' of the technology, along with ground-testing of components, including 'hardware-in-the-loop' simulation. According to MDA Director Kadish the increasingly sophisticated use of simulation and ground-testing has reduced the need for extensive flight-testing:

The full range of missile defense testing—from our extensive modeling and simulation and hardware-in-the-loop tests to our ground and flight testing—makes us confident that what we deploy will work as intended. We do not rely on intercept flight tests to make final assessments concerning system reliability and performance. Our flight tests are important building blocks in this process, but the significant costs of these tests combined with the practical reality that we can only conduct a few tests over any given period of time mean we have to rely on other kinds of tests to prove the system (Kadish, 2004).

Thus Major General Chris Anzalone of the MDA described the way flight-testing is now used as: 'Test to verify, not to discover' (Anzalone, 2006). However, if flight-testing is to verify the simulation models then it needs to be done in a range of conditions that is as similar as possible to, and as stressing as, operational use would be. Not all parts of the performance envelope can be explored in testing, but there should certainly be tests of different areas of the envelope, especially those that are operationally likely. Instead, most flight-tests conducted so far fall into a narrow range of the potential operational envelope as regards interceptor range and closing speed (see Coyle, 2000).

Fear of failure has led MDA to focus its efforts on ensuring flight-tests are successful (ie that they hit the target) rather than necessarily useful (ie that they might fail to hit the target, but nevertheless provide useful feedback that could

lead to improvements). For political reasons the overriding concern has been that flight-tests should succeed, not that they provide new data points. In most regards recent GMD flight-tests have remained confined to a narrow range of the potential operational conditions or have even become less demanding.

A significant example of this can be seen in the way that MDA has removed any decoys or countermeasures from recent tests. None of the GMD intercept tests since 2002 have included any decoys or countermeasures (Coyle, 2008, 16; Samson, 2008). According to testimony from former Pentagon test director Coyle: 'From a target discrimination point of view, during the past five years the flight intercept tests have been simpler and less realistic than the tests in the first five years' (Coyle, 2008, 16).

This goes against the logic of 'spiral development' in which the currently deployed system would be improved through feedback from progressively operationally relevant testing. That should mean testing in a wider range of realistic conditions, but this has not happened. For example, to date there has been no testing of the GMD system at night (Coyle, 2008, 17), but it can hardly be guaranteed that an enemy would overlook the age-old tactic of attacking under cover of dark. Given that the success of interception depends on the kill vehicle's ability to discriminate infrared signatures, the absence of sunlight heating of the reentry vehicles could be significant. Nor have there been intercept tests against tumbling reentry vehicles or against realistic decoys – objects that provide infrared signatures that can be difficult to distinguish from real warheads – although both these were originally planned to occur in 2001/2002 (Coyle, 2008, 17).

There has been one significant broadening of the flight-test envelope with the new intercept geometry used in the tests carried out in September 2006 and September 2007. Nevertheless, the General Accounting Office's March 2008

assessment of missile defense progress, noted that ‘tests of the GMD element have not include target suite dynamic features and intercept geometries representative of the operational environment in which GMD will perform its mission’ (GAO, 2008, 27). For example, all intercept tests to date have been against targets carried on minimum energy (the most efficient) trajectory missiles. Although it is well-known that both depressed and lofted trajectories can pose special problems for defences, they have not been incorporated into the flight-tests.

Finally, it is important to note that most test failures to date have been due to hardware problems and lack of reliability. Discovering such problems cannot be done ‘virtually’; it requires real flight-tests. To the extent that flight-test failures enable such problems to be discovered and remedied they are an important and necessary part of the development process.

Conclusions

The construction of a defense to protect the USA against ballistic missiles is a highly contested issue. Some critics doubt whether the threat is sufficiently great, especially given the high opportunity cost of devoting so much money to BMD. Others doubt whether the technology can work, and some missile defence supporters are much more enthusiastic about an approach based on space-based interceptors.

However, even amongst those who support both the overall goal of BMD and the approach of using ground-based interceptors, there remains disquiet about the way GMD deployment and testing has proceeded. These critics believe that the spiral development essential to the capability-based approach has not been followed through, and are surprisingly in agreement with many opponents of

BMD (such as the Union of Concerned Scientists) as regards the inadequate levels of realism in the flight-testing to date:

You know, that's a terrible accusation to make, that they got a flimsy system up in Alaska, and the whole theory of it being capability based was it's OK to deploy a system before its completed, ... but if you don't follow it up with spiral development you've kind of defaulted on the contract.^{xv}

This paper argues that there is a tension at the heart of GMD development with regards to flight-testing. Ironically, the strong desire of the Bush administration for early deployment may have undermined the role that flight-testing can play in improving the technology. Because the rush to deploy has created high expectations as regards to performance, every flight test now is inevitably a 'pubic experiment'. With Congress funding US BMD development to the tune of around \$10 billion per annum, and with the administration and the MDA claiming that the GMD system offers operational capability, there is a natural expectation that flight tests will demonstrate such a capability.

However, as it turned out, the decision to deploy coincided with a long hiatus in flight testing and a string of flight test failures, resulting in a period of almost four years - October 2002 to September 2006 - without a successful intercept. Rather than 'testing through failure' as originally planned, the MDA simply deployed a system without flight-testing. Moreover, there is concern that fear of failure in the flight-test programme means that tests are being designed to succeed rather than to learn, before a sufficient amount of learning has been achieved to justify claims of operational effectiveness in realistic conditions of use.

MDA now argues that early problems have been overcome and testing will become increasingly demanding. In December 2007 MDA Director Obering stated that: 'What we have to do now is to turn our attention to make sure we can fully wring out the system in a variety of operational and realistic scenarios. And that is what we will be doing over the next couple of years'. However, according to former test Director Phil Coyle: 'At the rate they are going ... it could take them 50 years' (both quoted in Butler, 2007).

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ⁱ For example, Memorandum for Dr Kissinger from Laurence E. Lynn, January 13, 1970. Subject: FY 71 Safeguard ABM Deployment Decision, National Archives, Nixon Presidential Materials Project, National Security Council Files, Box 840, ABM System 1/70 Vol III Memos and Misc, 1 of 2: 'What is both surprising and troubling is the view, apparently circulating in the Army's Ballistic Missile Defense Agency, that the Safeguard system would not make a significant contribution to Minuteman defense even during the interim period, from, say 1974 to 1978, when the threat may be great but new systems, either defensive or offensive, won't be available'; HAK Talking Points, Safeguard Review, NSC Meeting, January 27, 1971 attached to Memo for Dr. Kissinger from K. Wayne Smith, Subject: Talking Points on Safeguard, January 21, 1971. NSC Files, Box 842, Vol VI: 'We are justifying before the Congress a defense of Minuteman which we find is not particularly effective in defending Minuteman.'; Memorandum for the President from Henry Kissinger, Subject: Contractor Doubts about Safeguard, April 15, 1970. NSC Files, Box 841, ABM System Vol. IV: Bell Labs, the prime contractor responsible for building the system had the 'belief that the system, as it is being built, cannot adequately perform the missions assigned to it.'

ⁱⁱ Numbers of interceptors deployed is from MDA News Release, January 14, 2008. Accessed on 7 February 2008 at <http://www.mda.mil/mdalink/html/news.html>

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- iii See endnote 1.
- iv This could be said to be one out of three as the second test was initially aborted due to a problem with information from GPS satellites.
- v This success was much contested, and it is generally agreed now that few Patriots were successful in intercepting Scuds. For an overview, see Collins and Pinch, 1996, chapter 1.
- vi In the final year of the Clinton administration, FY01 funding was \$4.8 billion; under Bush it was \$7.8 billion for FY02, \$7.4 billion for FY03, and \$9.1 billion for FY04). See L. Gronlund, D. C. Wright, G. N. Lewis and P. E. Coyle III, Technical Realities: An Analysis of the 2004 Deployment of a US National Missile Defense System (Union of Concerned Scientists, May 2004), 6.
- vii The one exception was the short-range Patriot that remained the responsibility of the Army.
- viii This review was carried out by retired Air Force chief of staff, General Larry Welch of the Institute for Defense Analysis and reported in February 1998. See Graham, 2001, 28-29. The report is available at the MDA's website. www.mda.mil
- ix Interview with Philip E. Coyle III, Director, Operational Testing & Evaluation, 1994-2001, 28 November 2007.
- x IFT-13A was a test of Lockheed's BV+ booster but was postponed because of the production problems. IFT-13B was a similar test of the Orbital Sciences booster that was successfully carried out on January 26, 2004 (delayed from original date of July 2003).
- xi The members of the IRT were William Graham, a former presidential science advisor and deputy administrator of NASA; William F. Ballhaus, Jr, a longtime aerospace executive and former director of the NASA AMES centre; and Major General Willie Nance of the MDA.
- xii Anonymous source..
- xiii Interview with Bill Davis, former head of the Army's Advanced Technology Centre, and Deputy missile defence programme manager, 29 November 2006.
- xiv Ibid.
- xv Davis interview, op cit note 13.